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ASTROMETRIC STUDY OF THE STELLAR AND SUBSTELLAR POPULATIONS OF THE ORION STAR FORMING REGION

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RESUMEN

Presentamos los lineamientos generales y primeros resultados de un proyecto astrométrico para caracterizar, en términos de sus movimientos propios, las poblaciones estelares de baja masa y subestelar en 180 grados cuadrados de la región de formación estelar de Orión. Los primeros resultados de la reducción astrométrica ofrecen una incertidumbre en las coordenadas de $\sim 0.004''$ que, dada la cobertura temporal de 10 años de nuestras observaciones, permitirá la detección de movimientos propios de hasta $\sim 0.001''$/año.

ABSTRACT

We present the general guidelines and first results of an astrometric project for the characterization, in terms of proper motions, of the low-mass star and substellar populations in 180 square degrees of the Orion star forming region. The first results of the astrometric reductions show coordinate uncertainties of $\sim 0.004''$ which, with the 10 year span of our observations, will allow for the detection of proper motions down to $\sim 0.001''$/year.

Key Words: stars: formation — stars: kinematics — stars: low mass, brown dwarfs

1. INTRODUCTION

During the last decade the observational study of the formation of very low-mass stars and brown dwarfs has had an important development due to the availability of visual and infrared large-format cameras that have allowed to conduct deep and non-spatially-biased surveys of extended star forming regions (e.g. Luhman et al. 2007).

This contribution shows the general procedure of the astrometric part of a project to detect and characterize the very low-mass star ($0.2>M/M_{\odot}>0.072$) and substellar ($0.072 > M/M_{\odot} > 0.01$) populations of the entire Orion star forming region, with the goal of studing the nature of their formation processes and their early evolution.

The project is based on multi-epoch photometric observations in a region $\sim$ 180 square degrees in Orion that are being carried out since 1998 with the Quest-I camera (Baltay et al. 2002) installed on the 1 meter Schmidt telescope at the Venezuela National Observatory. Additionally we are conducting a spectroscopic survey using the Hectospec spectrograph (Fabricant et al. 1998) at the Smithsonian Astrophysical Observatory. At the beginning of this project we applied a coadding procedure in order to increase the signal to noise ratio of the images, and therefore allow the detection of very faint and late-type objects. As a result, the limiting magnitud of single-epoch images ($I \sim 19$) increased up to $I \sim 21$ and, together with infrared photometry from the Two Micron All Sky Survey (Skrutskie et al. 2006), allowed the selection of candidates to stellar and substellar members through the whole region of Orion. A first sample of these candidates has been spectroscopically confirmed as members. The initial results of the photometric and spectroscopic survey can be found in Downes et al. (2008).

Our photometric observations of Orion have a time span of $\sim$ 10 years and the accuracy reached during the first astrometric reductions suggests that they are usefull for the study of the stellar and substellar populations of this region. Here, we show the general motivations, first results and perspectives of a project to produce a deep astrometric catalogue ($I = 19$) with uncertainties in coordinates of $\sim 0.004''$ spanning $\sim$ 180 square degrees of the Orion star forming region.

2. THE RELEVANCE OF AN ASTROMETRIC CATALOGUE IN ORIÓN

In the context of the formation and early evolution of low-mass stars and substellar objects, the astrometric information is relevant for several reasons: (i) It allows a better selection of candidates to pre-main sequence population. In Orion such selection is beeing performed following photometric criteria only, which include the identification of pho-

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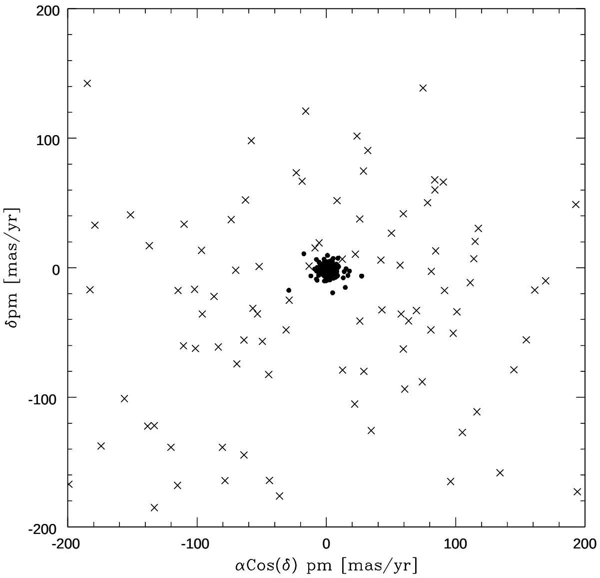

Fig. 1. Proper motions from the UCAC2 catalogue, of low-mass stars confirmed as Orion members by Briceño et al. 2005 (dots) and dwarf stars from the solar neighborhood from the compendium of Gelino, Kirkpatrick y Burgasser (crosses).

tometric variability for the selection of stellar candidates (Briceño et al. 2005) and the positions in color-magnitude and color-color diagrams for the selection of stellar and substellar candidates (Downes et al. 2008). In the case of very low-mass stars and brown dwarfs in the dispersed Orion subregions, the spectroscopic confirmation of candidates has allowed us to stablish that 75% of the candidates selected photometrically are real members of Orion while the remaining 25% are mostly field dwarf stars from the foreground (Downes et al. 2008). As an example of how useful the astrometry is for the distinction of both populations, Figure 1 shows a diagram of proper motions of low-mass stars from the UCAC2 catalogue (Zacharias et al. 2004) ($M > 0.6\ M_{\odot}$) confirmed as members of Orion (Briceño et al. 2005) and field dwarf stars with spectral types from M8 to L4 from the Gelino, Kirkpatrick and Burgasser compendium (`DwarfArchives.org`). The latter are posible contaminants of our sample of very low-mass star and substellar members of Orion. The kinematical behavior of both populations is different and the photometric candidates showing proper motions inconsistent with the ones in Orion can be discarded as candidate members of the region. This improved selection of candidates is important for the study of the Orion population because the low spatial density of candidates, their faint magnitudes, spectral distributions with the highest emissions to near infrared wavelenghts and the spatial extension of the region do not allow a spectroscopic survey of the entire region to be performed in a reasonable period of time. (ii) On the other hand, the proper motions and spatial distributions of pre-main sequence objects offer information about the dynamical processes occurring during their formation and early evolution (Whitworth et al. 2007). (iii) Finally, the Orion star forming region is composed of several subregions at different evolutionary stages that offer an ideal view on the evolution of stellar and substellar objects during the first 10 million years of their lifetimes. In some cases, the distinction of these subregions using photometry alone is a difficult task due to the uncertainty in the distances and their possible overlap (Briceño et al. 2005). Adding the proper motions to the photometric data the membership probability can be established with high accuracy.

Moreover, the available astrometric surveys that cover the entire Orion region have a limiting magnitude lower than that needed to observe very low-mass stars and objects down to the substellar limit. Figure 2 shows the I vs.R-I color-magnitude diagram constructed with observations from our survey in a subregion of Orion spaning 25 square degrees (limiting magnitude $I \sim 19$) with the stars of the UCAC2 catalogue (limiting magnitude $I \sim 14.5$). The objects placed above the 10 million years isochrone are candidate stars for the pre-main sequence Orion population. Out of these, only objects with masses greater than 0.6 $M_{\odot}$ have proper motions available in the UCAC2 catalogue.

3. ASTROMETRIC REDUCTION

The astrometric catalogue is being developed using only images obtained from the Orion Variability Survey (OVS) (Briceño et al. 2005) performed with the Quest-I camera and the 1m Schmidt telescope at the Venezuela National Observatory using V, R and I Cousins filters. All the observations have been obtained in *Drift-Scan* mode (DS), in which the telescope is fixed, the objects have a movement due to the sidereal motion and they keep their real shapes due to the alignment of the pixel rows with respect to the apparent motion and a read out rate of the CCD sinchronized with the linear velocity that the stars have in the focal plane of the telescope. The 16 CCDs of the mosaic are 2048×2048 pixel arrays of $15\mu m$ each, that produce a scale of $1.02''$/pixel and have a spatial coverage of $\sim$ 0.36 square degrees. During a DS each CCD of the array produces an image whose width in declination is 2048 pixels

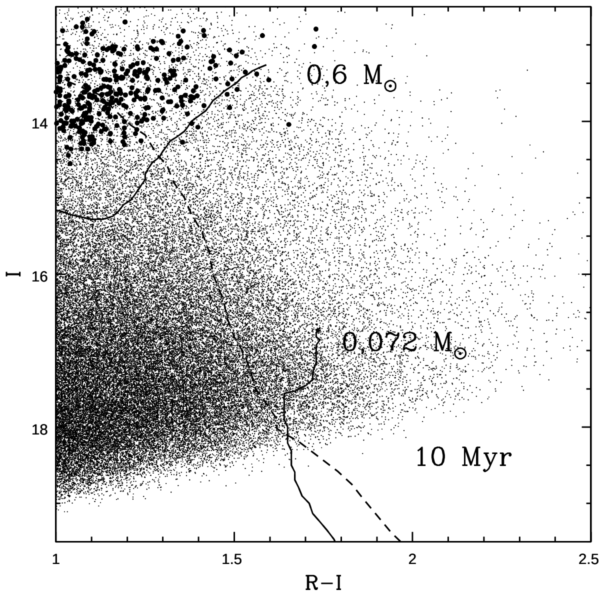

Fig. 2. I vs.R-I color-magnitude diagram of point sources detected in a typical DS observation from OVS in 25 square degrees of the Orion star forming region. Small dots are objects from our survey data base and big dots represent objects from the UCAC2 catalogue in the same region. Solid lines indicate evolutionary tracks of 0.6 $M_\odot$ and 0.072 $M_\odot$ (substellar limit) and the dashed line indicates the 10 million years isochrone which represent the upper age limit for the Orion region. The evolutionary tracks and isochrones are from Baraffe et al. 1998 and were corrected with a distance modulus of $m - M = 8.21$ representative of the mean distance to the Orion subregions.

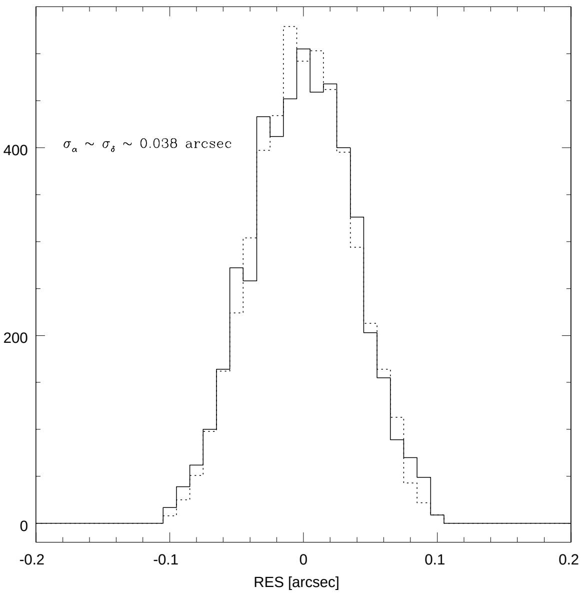

Fig. 3. Typical distribution of the residuals in right ascention (solid line) and declination (dotted line) between the catalogue and computed coordinates for 45 images obtained by the same ccd in a single DS. Standard deviations for both distributions are shown. The mean number of stars used to compute the solutions places the accurracy at $\sim 0.004''$ for both coordinates.

and its length in right ascension depends on the duration of the observation. In order to save the data, each image is cut in right ascension every 2048 pixels, resulting in a set of images whose dimensions are the physical ones of the CCD. In the end, a DS observation produces 16 series of images, one per CCD, in which there is quasi simultaneous information in four different filters. For single observations in DS mode, the instrument reaches a limiting magnitude of $I \sim 19$ with completeness to $I \sim 18$, which in Orion allows the observation of substellar objects with masses down to $\sim 0.05\ M_\odot$. The completeness magnitude corresponds to the magnitude at which the logarithm of the number of objects as a function of magnitude departs from linear behavior.

The OVS data base is composed of ~ 200000 images and the astrometric reduction needs to be performed automatically. We have integrated a set of astrometric and image processing tools to produce an astrometric reduction task that works independently on each image produced by each CCD of the mosaic during DS observations with arbitrary length. For each image the task detects the point sources, identifies which point sources correspond to stars in the UCAC2 astrometric catalogue, and produces a catalogue of reference stars based on the astrometric matrices that are computed following the scheme of Stock (1981). The convergence to the higher accuracy solution for each image is done following an iterative process that consists in the analysis of the residuals in right ascention and declination between the computed coordinates and the coordinates from the UCAC2 catalogue, the rejection of the objects that show deviated residuals and the new computation of the solution. Once computed solutions for all the images are obtained by the same CCD during a DS, all the reference stars used to compute the solutions are used to produce the pattern of the distortions added by the system, in the same standard way in which distortion patterns are used for astrometric reductions of overlapped field observations. This pattern includes the distortions produced by the optical system and the curvature effects in the movement of the objects during the DS. The pattern is computed using the (x, y) coordinates in the image and the residuals between computed and catalogue coordinates. The number of stars per CCD used during this computation is typically 3000 for a DS of 1 hour right ascension lenght.

Figure 3 shows the typical distributions of residuals between coordinates from the catalogue and coordinates computed with the automatic task for the 45 images obtained by a single CCD during a DS of $\sim$ 1.5 hours length. The standard deviation of both distributions is $\sim 0.04''$ and the typical number of reference stars used for the computation of each individual solution $\sim$ 120, placing the resulting uncertainity at $\sim 0.004''$ for both coordinates.

4. SUMMARY AND PERSPECTIVES

The first results of the automatic astrometric reduction of the OVS database results in an accuracy level of $\sim 0.004''$ in both coordinates. The 180 square degrees covered by OVS are divided in 6 strips at constant declination, each one with a time span of between 7 and 10 years. The accuracies obtained during the computation of coordinates and the time span of the observations allow the detection of proper motions down to $0.001''$/yr. This accuracy in proper motions and the limiting magnitude of our observations allow the selection of candidate members and the study of the kinematics of the confirmed members of Orion in a mass interval of $0.8 < M/M_{\odot} < 0.05$. A detailed explanation of the procedures followed during the astrometric reduction and the catalogue of proper motions for the first subregion of Orion will be presented in Downes et al. (2008).

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